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INFLUENCE OF CRACK WIDTH AND DEPTH ON MAGNETIC FLUX LEAKAGE FIELDS

TECHNICAL REPORT NO. WAL TR 148.1/2

BY

PATRICK C. McELENEY

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WATERTOWN ARSENAL
WATERTOWN 72, MASS.

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TITLE

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ABSTRACT

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specimen. However, the magnitude of the contribution due to width varia-
tions is large enough to cause spread in data in voltage versus crack
depth graphs. More refined techniques of signal analysis and a more ac-
curate determination of the distribution of magnetic flux about discontinui-
ties are required to improve the precision of measurement of crack depth
by the magneto-inductive method.

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REPORT APPROVED
Date 1 Sept 69
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INTRODUCTION

Previous work by Kodis and Darcy[1] has disclosed that the amplitude of the signal from a crack detected by magneto-inductive techniques is a positive increasing function of crack depth which is not always linear. Additional studies by Hastings, Darcy, and McEleney[2] resulted in a calibration curve of actual crack depth versus signal strength which demonstrated that there is a definite relationship between the two. Considerable spread in the data, believed to result from numerous uncontrolled variables in the test, was noted. In an effort to determine the effect of some of the variables existing in the specimen, such as chemistry, heat treatment, and residual magnetic field level, studies were conducted by McEleney[3] on milled slots in lieu of actual stress cracks. Although changes were noted which could account for the spread in the previous data, refined techniques are required for quantitative measurement of the influence of these variables on the measurement of crack depth. This project was conducted to improve existing techniques and to investigate certain variables encountered in the measurement of crack depth by the magneto-inductive method.

The purpose of this present investigation was to determine the effect of crack width and depth variations on the amplitude of signals detected by pickup coils scanning the surface of a magnetized specimen.

PREPARATION OF SPECIMEN

A block of SAE 4130 steel was forged, rough machined, and heat treated to give metallurgical and physical properties similar to that found in gun tubes. The block was finish machined to 6" x 8" x 3" with a section, 3" x 5" x 3", removed from the center. A coil of wire (1500 turns) was wound around the base (Figure 1). Three slots, 2 inches apart, were milled in the top of the block. One slot was for calibration of the equipment and remained fixed at 0.100-inch deep and 0.004-inch wide throughout the tests. The second slot was for depth studies and remained at a constant width of 0.004 inch throughout. The depth was increased in various increments from 0.010 inch to 0.118 inch. The third slot was for width studies and remained at a constant depth of 0.100 inch throughout the measurements. The original width of 0.004 inch was increased in increments of 0.002 inch to 0.012 inch.

A set of aluminum V-blocks was made for accurate positioning of the search unit used in the measurements. The V-blocks were held fixed in relation to the specimen by four pins on each side (see Figure 1). A brass bolt passed through he entire assembly to hold the V-blocks firmly in place (Figures 2 and 3). Two aluminum bars, with two bolts each, were used to hold the search unit firmly in position on the V-blocks (Figures 2 and 3). Shim stock was used for setting the height of the search coil above the specimen and three wood positioners were used to set the search coil over a specific portion of the crack.

APPARATUS AND EXPERIMENTAL SETUP

The following apparatus was used:

    Dumont Type 304 Oscilloscope with Voltage Calibrator

    Powercon Battery Eliminator

    0 - 2 Amperes Ammeter

    385 Ohm, 2 Watt Rheostat

    360 RPM Motor with Controller

    Search Unit

The equipment was connected as shown in Figures 3 and 4.

The technique used in testing depends on the magneto-inductive effect. This effect is based on the principle that, in a circumferentially magnetized ferromagnetic material, a crack at any angle to the direction of the magnetic field has associated with it a magnetic leakage field which is external to the specimen itself. If the surface of the piece is scanned by a suitable coil, a voltage will be induced in this coil which is dependent on the speed and direction of the coil motion, coil geometry, core material, number of turns of wire in the coil, and strength and orientation of the leakage flux.

In this setup a variable d-c source supplies the current to the coil wound on the specimen. This current is controlled by a rheostat and measured by means of an ammeter. A motor (shown at the right in Figure 3) turns the pickup coil in the search unit at a speed of 360 revolutions per minute. The signal detected by the coil is picked off slip rings at the end of the search unit by a pair of brushes and displayed on the cathode ray oscilloscope. The signal level is measured by means of a voltage calibrator used in conjunction with the oscilloscope.

TEST PROCEDURE

The specimen was brought to a cyclically magnetized condition before each set of readings. This was accomplished by means of a reversing switch (see Figure 4). Care was taken to have the current flow through the magnetizing coil in the same direction for all measurements. The The readings were taken at the highest value of current available and as the current was reduced in increments of 0.1 or 0.2 ampere until 0 was reached. Readings were taken on the calibration slot before and after each measurement on the depth and width slots, to make sure that initial values obtained were repeated. As the measurements proceeded only a spot check taken at 1.0 ampere was required to determine that the results were reproducible.

As indicated in the section on specimen preparation, measurements were made on the depth slot at depths from 0.010 inch to 0.118 inch in

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various increments with the width fixed at 0.004 inch. Readings were made at three positions along the slot: Position A, 5/8 inch away from the center of the specimen, Position B at the center, and Position C, 5/8 inch on the other side of the center. The search coil was set at these locations by means of small wood positioners which permitted rapid and accurate movement of the coil from one location to another. A positioner was placed against the edge of the specimen and the unclamped coil moved until it touched the opposite edge of the positioner. Here the wing nuts on the clamps were tightened and the positioner removed. The height of the coil was fixed at 0.005 inch above the specimen and this was checked before each measurement by means of 0.005-inch brass shim stock.

Measurements were made on the width slot, starting at a width of 0.004 inch which increased to 0.012 inch, in increments of 0.002 inch with the depth of this slot fixed at 0.100 inch. Readings were made at three positions along the slot as indicated in the preceding paragraph for the depth slot, starting at the highest current value and decreasing in increments of 0.1 or 0.2 ampere until 0 was reached.

RESULTS AND DISCUSSION

The procedure used in this study avoided some of the possible causes of inconsistencies in earlier work. The specimen was designed so that the slot variations were at two locations in the specimen, one for the width changes and the second for the depth changes. Previously several slots of varying sizes were used and large magnetic differences in the material prevented quantitative measurements. Greater care was exercised in preparing this specimen to prevent the occurrence of bothersome stress conditions. Residual stresses introduced in the machining operation were a second possible cause of inconsistencies in earlier work, and large differences were noted in the residual magnetic field from specimen to specimen (Reference 3). Although the residual magnetic field level is related to the variables considered there (heat treatment, magnetization level and chemistry), it is of little consequence in this present study, so a continuous field was used.

Inconsistencies caused by facsimile recorders and the quality of paper used in these recorders were avoided. Direct voltage measurements were made using an oscilloscope and voltage calibrator.

The variable quantities studied here are slot width, slot depth and magnetizing field strength. Position of measurement on a slot and height of the search coil above the slot were held constant.

The induced voltage versus depth of slot measurements are given in Table I and selected magnetizing current values of these measurements at Position B are plotted in Figure 5. The induced voltage versus width of crack measurements are given in Table II and selected magnetizing current values of these measurements at Position B are plotted in Figure 6. The

voltage versus depth curve (Figure 5) is very similar to previous plots of these variables. The relationship is not linear but the voltage is a positive increasing function of slot depth.

The voltage versus width curve (Figure 6) shows that the voltage is a positive increasing function of width in the range up to 0.008 inch. The magnitude of the width effect is smaller than that of depth effect in the range of interest here, but it is much larger than indicated in previous theoretical studies. Indeed the magnitude of the width variations may have caused much of the spread in the data reported by Hastings, Darcy, and McEleney (Reference 2).

The voltage versus width curve decreases sharply at Position B from 0.010 inch to 0.012 inch. This decrease suggests that the shape of the magnetic leakage field is an important factor in the voltage level measured. Mechanical deficiencies in the experimental procedure might account for a decrease in the accuracy of readings for a quantitative evaluation. However, the readings would tend to be on the low side because of difficulties in keeping the center of the slot in one position in the machining operation in which the width is increased. Further difficulties are experienced in setting the search coil in the position of maximum voltage deflection. However, neither of these conditions would account for a voltage decrease of the magnitude detected, if it accounted for any decrease at all.

It is reasonable to expect that the voltage would drop off with a flattening out of the magnetic leakage field about the slot. The voltage amplitude is dependent on the number of flux lines cut per unit time $(d\phi/dt)$, and not on the total number of flux lines cut. Additional information must be obtained on the shape of the magnetic leakage field associated with the various shapes the slot may assume, to improve the measuring technique. The amplitude of the induced signal, therefore, does not furnish enough information to permit extremely accurate depth measurements.

The measurements on the width slot at points A, B, and C for various widths and magnetizing current values are plotted in Figure 7, and on the depth slot at various depths in Figure 8. There are many inconsistencies noted in these readings. Some curves are higher at the ends and others are lower. The trend is towards lower readings at Positions A and C than in the middle of the slot.

A change of magnetizing current causes the graphs of voltage versus width or depth of slot to trace out nearly parallel curves as indicated in the plots of 1.0 and 0.6 ampere shown in Figures 5 and 6.

SUMMARY

1. The depth of a crack has more effect on the amplitude of the induced voltage than the width in the range of values studied.

2. Variations in the width of crack will cause significant spread in the voltage versus depth graph.

3. The amplitude of the voltage does not furnish enough information to separate depth variations from other variables, such as width, which may be present.

4. The shapes the magnetic leakage field assumes for different crack geometries must be known so that the effect of crack dimensions on the voltage measurements can be evaluated.

RECOMMENDATIONS

1. The flux pattern of the magnetic leakage fields associated with typical crack geometries should be determined, using techniques such as magnetic field plotting.

2. Other types of analysis on the induced signal should be developed to obtain sufficient information to improve the accuracy of crack depth measurement.

TABLE I

VOLTAGE READINGS FOR DEPTH SLOT (PEAK TO PEAK VOLTS)

POSITION A

Depth (In.)	Magnetizing Current (Ampere Turns)							
	1800	1650	1500	1200	900	600	300	0
.010	-	-	-	-	-	-	-	-
.020	-	-	-	-	-	-	-	-
.040	.145	-	.135	.115	.10	.085	.07	.06
.060	.16		.13	.12	.11	.09	.07	.06
.080		.32	.305	.255	.23	.18	.155	.105
.100		.41	.395	.36	.325	.265	.205	.13
.118	Cutting tool broke off in slot at this position							

POSITION B

Depth (In.)	1800	1650	1500	1200	900	600	300	0
.010	-	-	-	-	-	-	-	-
.020		.005(estimated)	-	-	-	-	-	-
.040	.155		.13	.115	.095	.085	.07	.06
.060	.18		.17	.16	.125	.11	.09	.07
.080		.315	.305	.26	.28	.18	.14	.115
.100		.41	.39	.365	.315	.27	.19	.125
.118		.52	.49	.445	.40	.345	.265	.18

POSITION C

Depth (In.)	1800	1650	1500	1200	900	600	300	0
.010	-	-	-	-	-	-	-	-
.020	-	-	-	-	-	-	-	-
.040	.135		.125	.105	.09	.075	.065	-
.030	.15		.15	.14	.11	.09	.08	.06
.080		.27	.255	.235	.19	.155	.125	.09
.100		.28	.27	.24	.21	.195	.14	.10
.113		.375	.33	.305	.27	.23	.185	.16

TABLE II

VOLTAGE READINGS FOR WIDTH SLOT (PEAK TO PEAK VOLTS)

POSITION A

Width (In.)	Magnetizing Current (Ampere Turns)							
	1800	1650	1500	1200	900	600	300	0
.004		.25	.21	.17	.135	.11	.085	.065
.006			.305	.26	.21	.17	.145	.115
.008	.365		.325	.285	.26	.205	.17	.145
.010	.33		.315	.29	.24	.20	.11	.125
.012		.285	.21	.14	.08	.05	.035	0

POSITION B

Width (In.)	1800	1650	1500	1200	900	600	300	0
.004		.285	.265	.225	.19	.145	.10	.095
.006	.355		.31	.265	.21	.17	.105	.115
.008	.435		.395	.33	.285	.24	.207	.17
.010	.415		.40	.36	.275	.24	.17	.145
.012		.26	.22	.13	.085	.05	.035	0

POSITION C

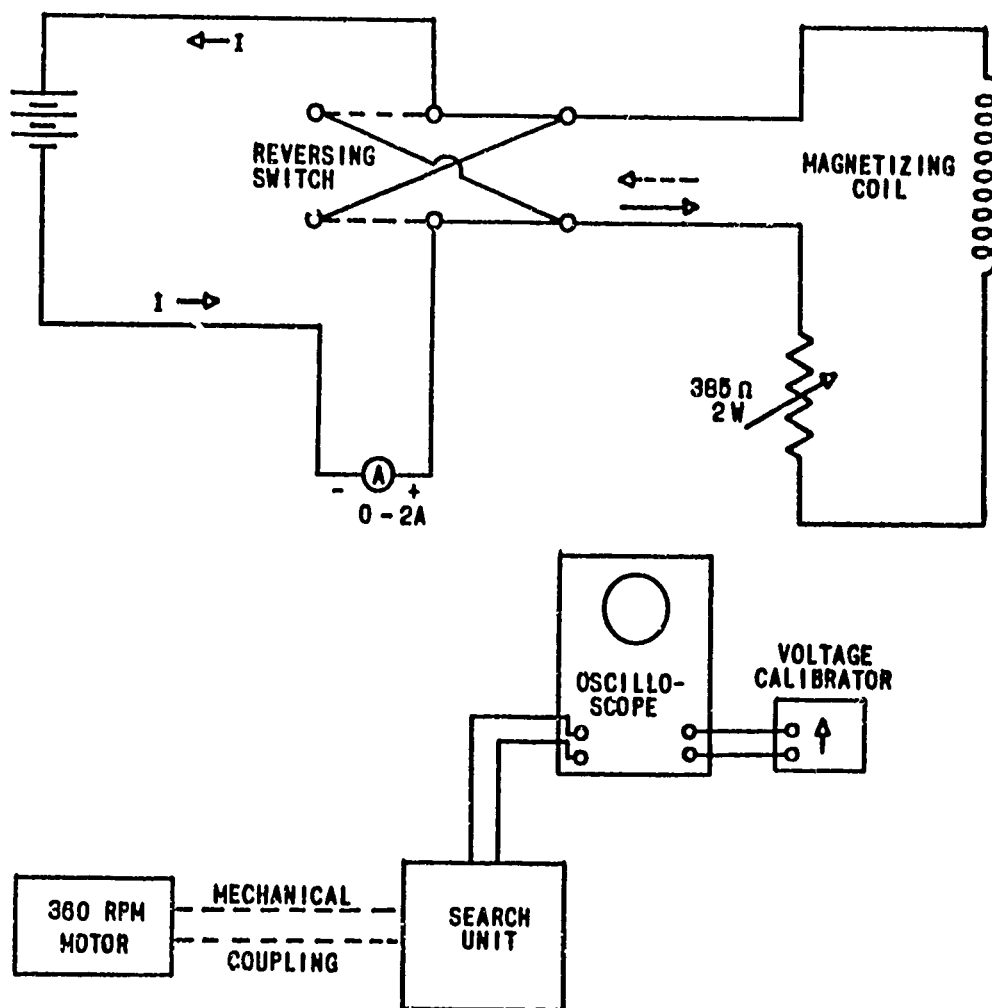| Width (In.)	1800	1650	1500	1200	900	600	300	0
.004		.25	.235	.20	.16	.12	.10	.075
.006	.35		.315	.275	.225	.195	.155	.12
.008	.405		.365	.32	.27	.24	.205	.175
.010	.40		.395	.36	.29	.24	.195	.15
.012		.255	.19	.145	.12	.07	.035	0
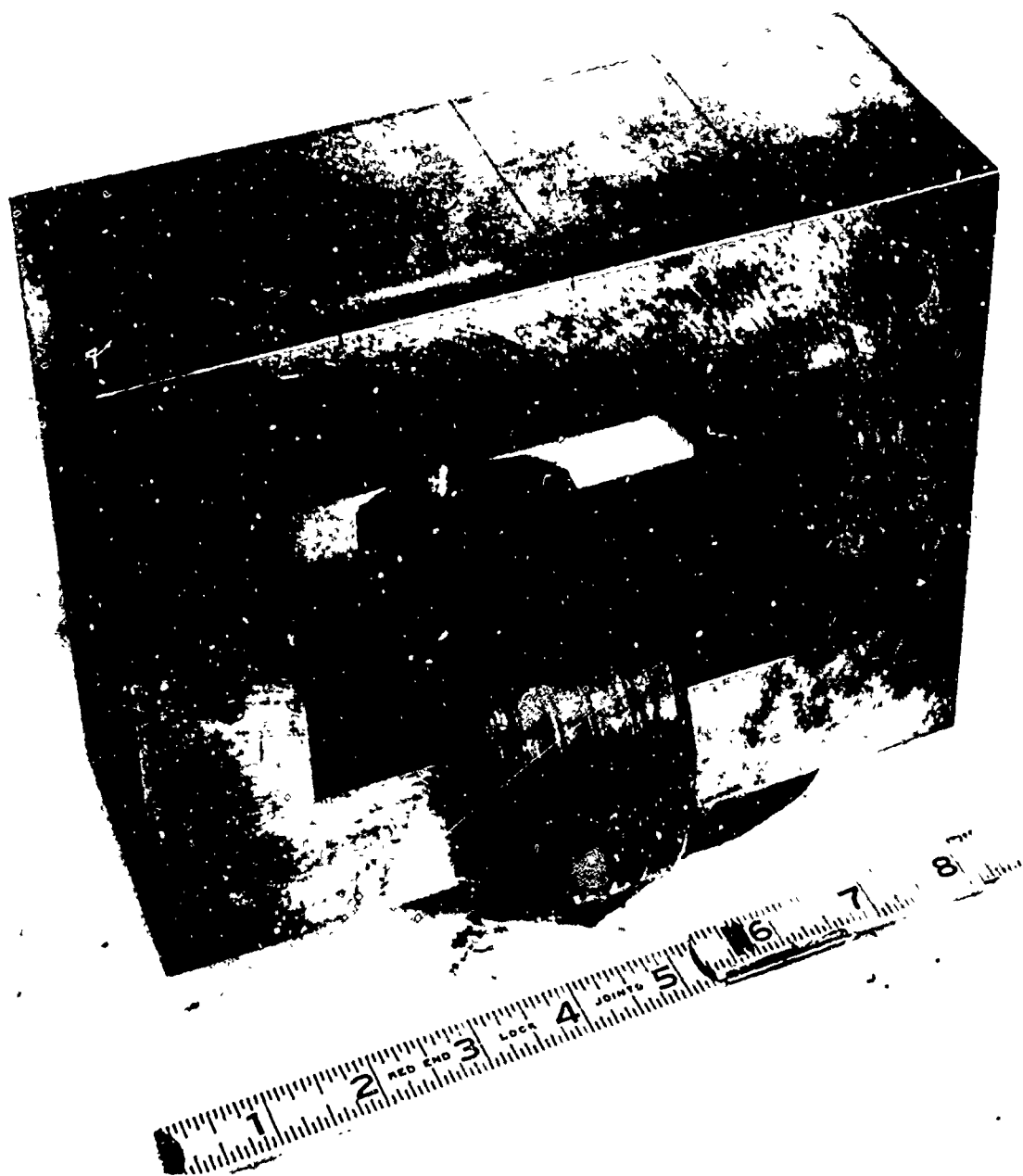
SPECIMEN, UNMOUNTED, SHOWING MAGNETIZING COIL
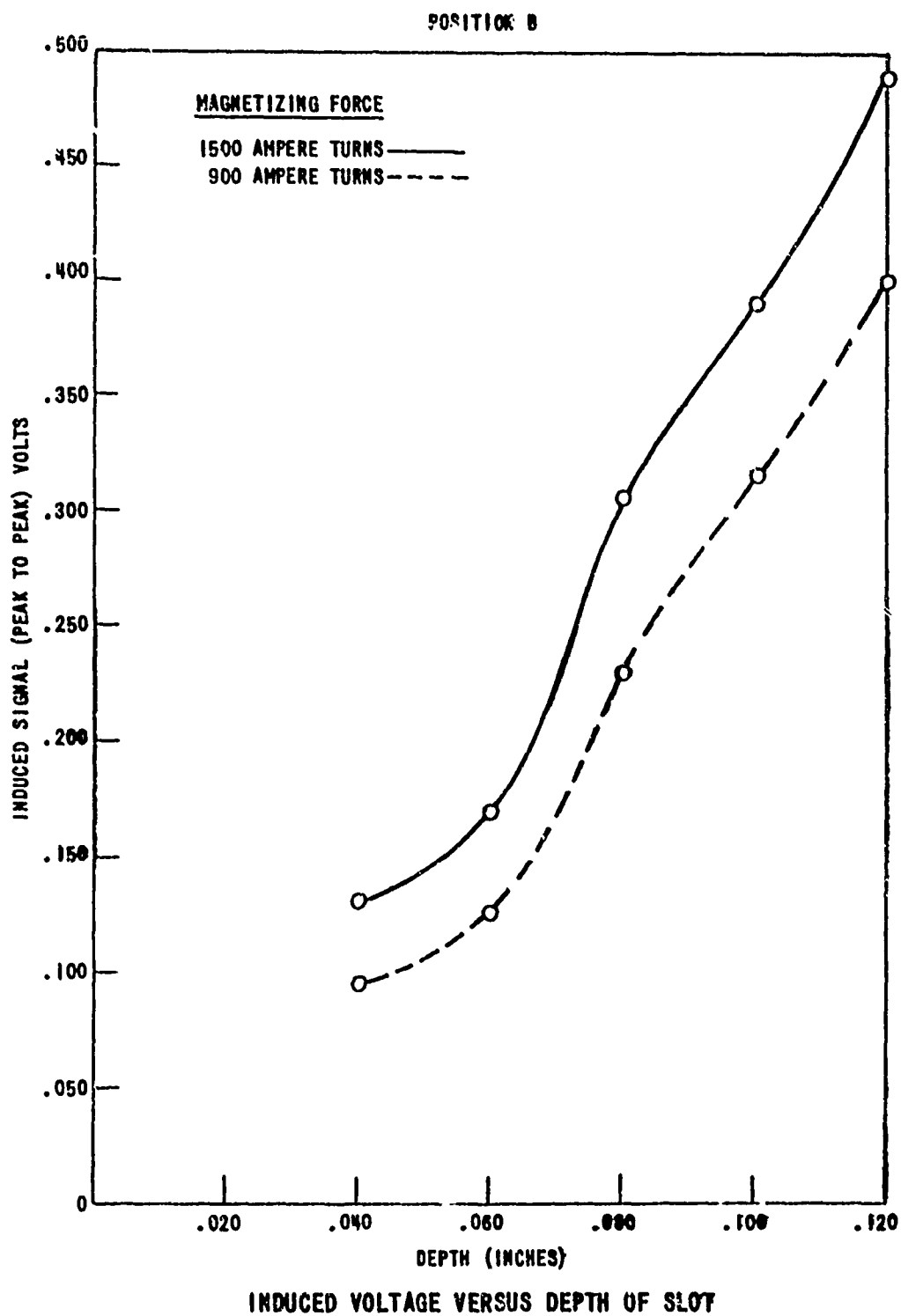
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FIGURE 1
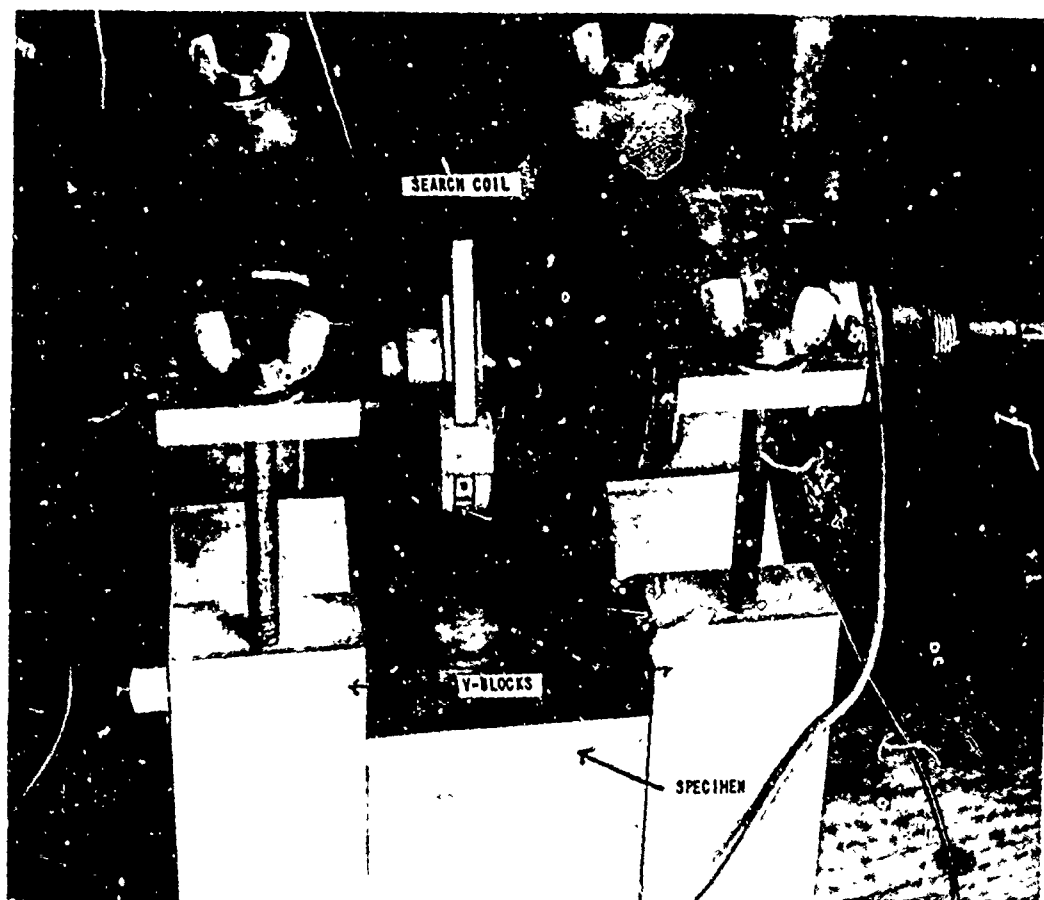
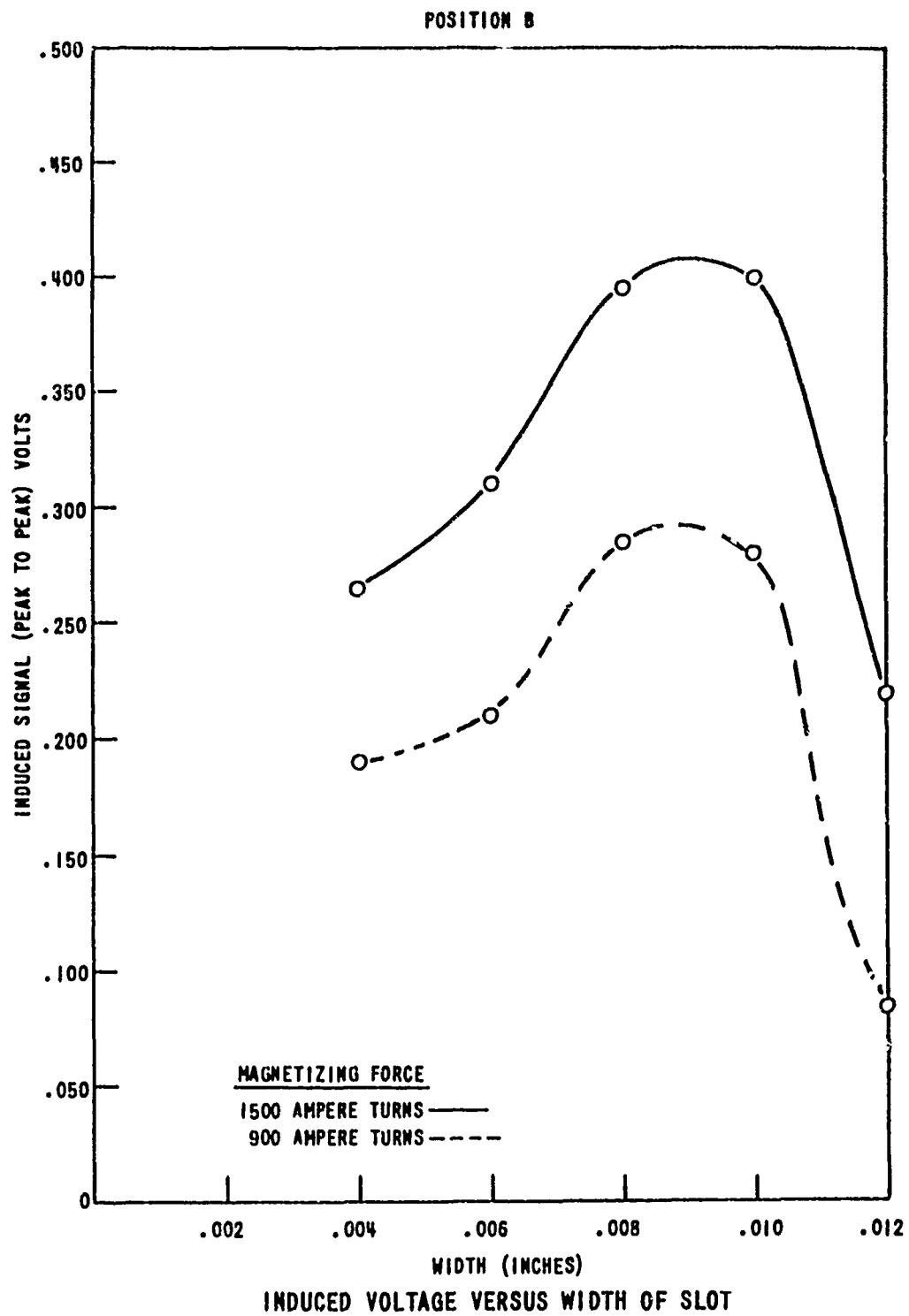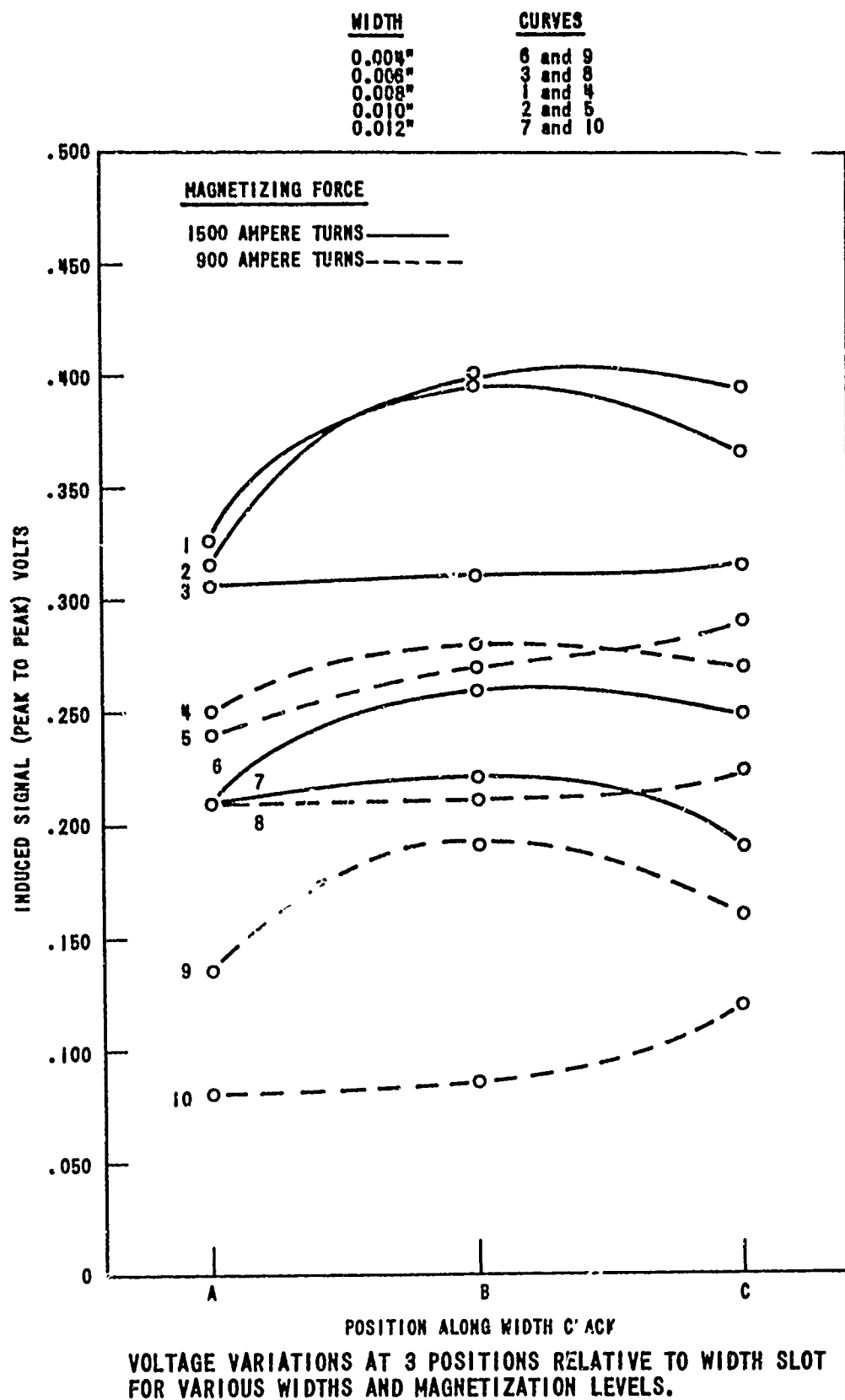SPECIMEN MOUNTED IN V-BLOCKS WITH SEARCH UNIT CLAMPED IN POSITION

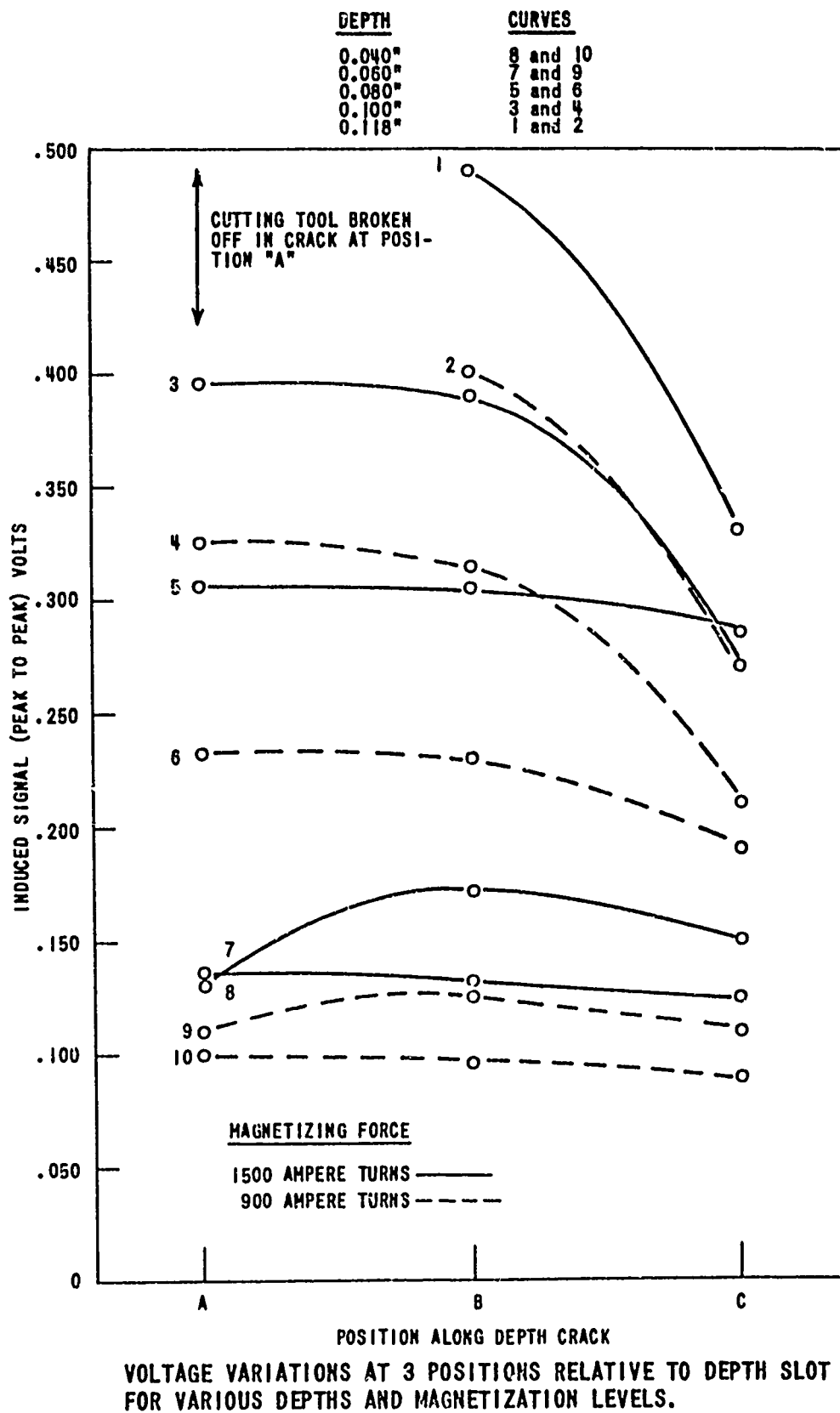-10-

FIGURE 2

EXPERIMENTAL SETUP

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FIGURE 3

ELECTRICAL CIRCUIT CONNECTION

FIGURE 4

INDUCED VOLTAGE VERSUS DEPTH OF SLOT

FIGURE 5

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POSITION B

INDUCED VOLTAGE VERSUS WIDTH OF SLOT

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FIGURE 6

VOLTAGE VARIATIONS AT 3 POSITIONS RELATIVE TO WIDTH SLOT
FOR VARIOUS WIDTHS AND MAGNETIZATION LEVELS.

FIGURE 7

DEPTH	CURVES
0.040"	8 and 10
0.060"	7 and 9
0.080"	5 and 6
0.100"	3 and 4
0.118"	1 and 2

VOLTAGE VARIATIONS AT 3 POSITIONS RELATIVE TO DEPTH SLOT
FOR VARIOUS DEPTHS AND MAGNETIZATION LEVELS.

FIGURE 8

REFERENCES

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